HANDS-ON UNIVERSE™

SUPERNOVA LIGHT CURVES Unit

In the spring of 1994 several HOU students were studying M51, the spiral galaxy also known as the Whirlpool Galaxy. Various HOU images had been requested throughout February and March, and in early April, two girls at Oil City High School in Pennsylvania received an important phone call. They had serendipitously obtained the first images of a supernova in M51.

A supernova is the violent process that a very massive star undergoes when it dies. Many people think of supernovae as explosions, and in some cases this is true, but some stars implode rather than explode when they die. In either case, the brightness of the star increases dramatically during a supernova and then fades off continually until it is no longer visible. The rate at which the brightness increases and then fades is one indicator of what type supernova has occurred and what type of star is involved. In the *Supernova Light Curve Unit* you will use images taken by HOU students to create and study a plot of the brightness of a supernova as it changes over several weeks. This plot is called a light curve.

In order to measure the brightness variation of the supernova itself, you must eliminate effects caused by changing observing conditions. This is done through the use of a reference star. Since the reference star and the supernova are within the same image, the observing conditions are identical for both objects. The reference star should have constant luminosity which means if the observing conditions remain constant from one night to the next, the Counts of the reference star will remain the same. In general, observing conditions do change, so the number of Counts measured for the reference star will increase or decrease depending how much light the atmosphere lets through on a given night.

If the luminosity of the supernova candidate were to remain constant from image to image even though the observing conditions change, the ratio of Counts for the supernova and the reference star would also remain constant - the candidate is not a supernova. However, for a supernova that grows brighter and then fades, the brightness ratio changes accordingly. By measuring this ratio for each image, you can plot the true light curve for the supernova.

Activity: Plotting the Light Curve of SN1994i

Computer setup: Open the HOU-IP software. The images you will use are located on the CD drive. Click the File Open icon and locate the set of 11 images named as follows: SN_M51_day_0 through SN_M51_day_-47. Open "day 0", "day 2" and "day -47". You will use the others in just a few minutes.

These twelve images of the supernova were taken in April and early May of 1994. The date of observation and other information are listed under **Image Info** for each image. They have been named, however, so that the night of the observation is contained in the title. The image, "day 0", is the first day of the supernova; "day 2", two days later; "day -47" is the view of the galaxy 47 days before the supernova "went off".

First, look at image "day -47". This is the "normal" appearance of the Whirlpool Galaxy. Astronomers who are used to seeing this image will notice nothing unusual about it.

Now look at image "day 2". **What do you see that is noticeably different? Where is "it" located? Identify this location in some way in reference to the galaxy nucleus.**

This was the astronomy world's first indication that a supernova was going off in M51, and they began observing on a regular basis after that. Simultaneously it was discovered that the students in Oil City, Pennsylvania, had requested an image of M51 two days earlier. When that image was examined in the region above, they all saw what you can now see for yourself**. Look at the "day 0" image very closely at the location you identified in the day 2 image. What do you notice?……perhaps the beginnings of the supernova?!** This was a very fortuitous finding, because the astronomers could now measure a near complete light curve. You will now do that yourself.

1. In each image measure the brightness of the supernova and the brightness of a reference star. We recommend that you use the bright star at approximately 45° to the lower left of the galaxy core as the reference star. You may use **Auto Aperture** to measure the Counts for this star, but you should use **Aperture** for the supernova since it is so close to the center of the galaxy. You will find this tool under the **Data Tools** menu. For the **Aperture** settings use a Radius of 7 and a Sky Radius of 14. Click OK and place the cursor on the center of the supernova.

Record the Counts for both the supernova and the reference star on the chart two pages away. Repeat this procedure for all 10 images. (Day "0" through Day "36")

2. Divide the Counts for the supernova by the Counts of the reference star to get the Count ratio for each night

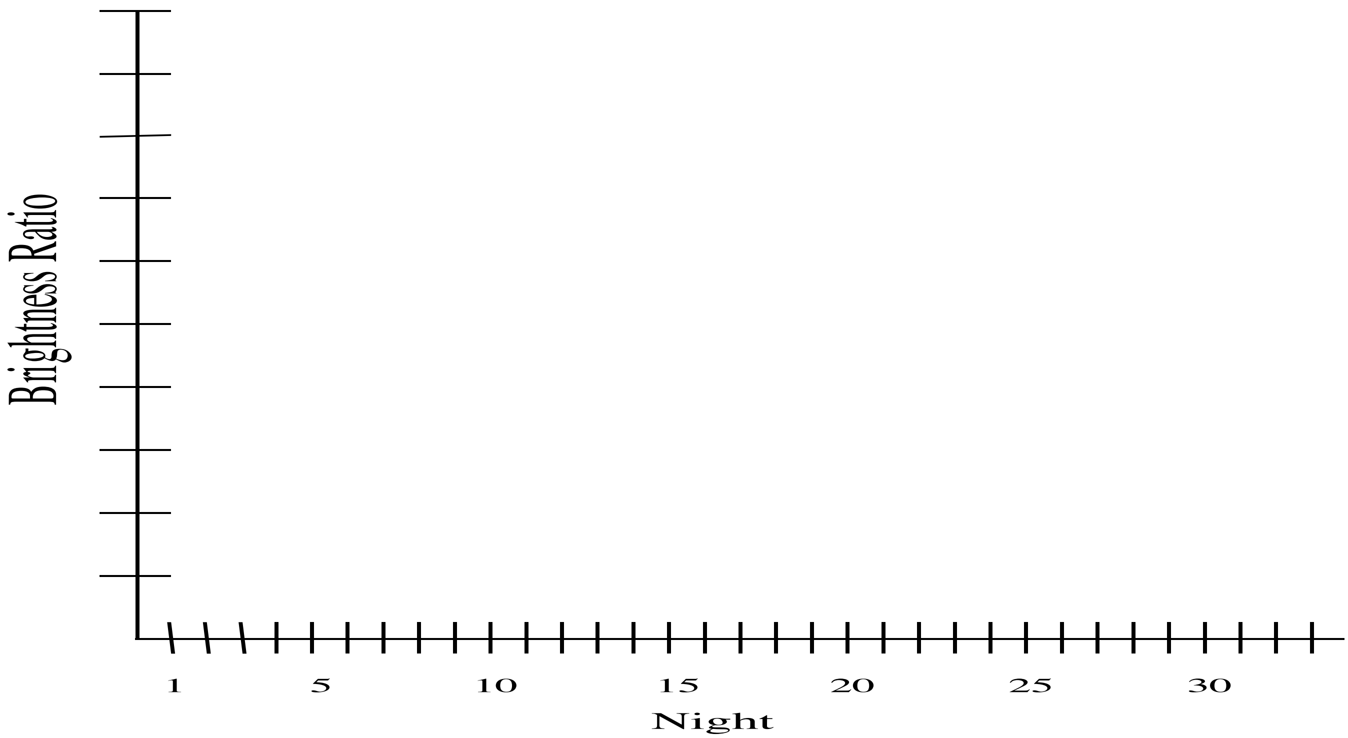
3. Make a light curve for SN1994i by plotting the Count ratio versus night number. You may want to use the graph paper in your notebook rather than the one attached.

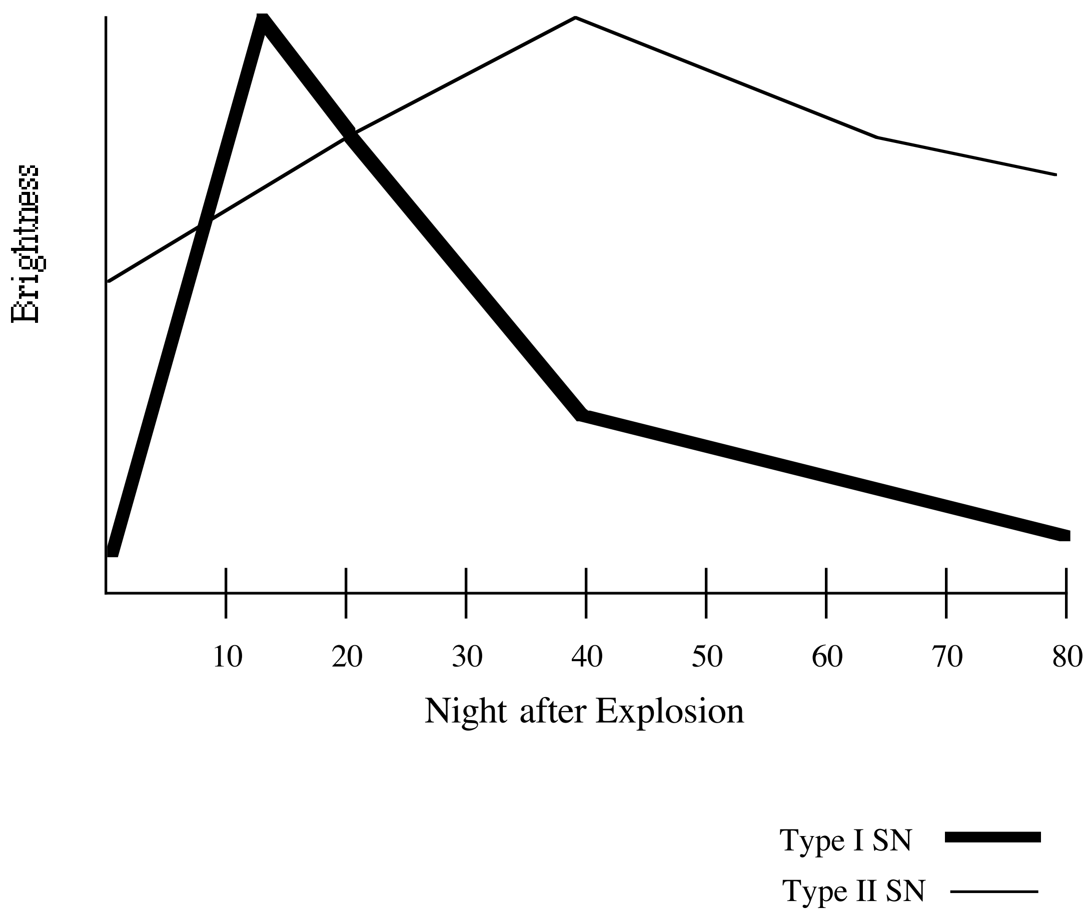
Data sheet for Plotting the Light Curve of SN1994i

Image	Night Number	Counts of Supernova	Counts of Reference Star	Brightness Ratio
NOT NEEDED				

4. Compare your light curve with those shown on the following page and infer the type supernova for SN1994i.

5. From your light curve you can determine the day (night) of maximum brightness of the supernova. Use that image to compare the brightness of the supernova to the brightness of the galaxy core. Use **Aperture** with a Radius of 16 and a Sky Radius of 48 to measure the Counts of the core. You already have the Counts of the supernova from an earlier measurement. The core of M51 is considered to be equivalent to approximately one billion Suns. **How many times more luminous than the Sun is this supernova at maximum brightness? Express your answer in number of Suns.**


Brightness Ratio
1
5
10
15
20
25
30
Night


Brightness
10
20
30
40
50
60
70
80
Night after Explosion
Type I SN
Type II SN

SCIENCE OF A SUPERNOVA

Introduction

Suppose you were out looking at the sky on a dark, starry night and suddenly you saw a star that wasn't there a moment earlier? You might think your eyes were playing tricks on you. You could check by taking a photograph of the region of the sky and comparing it to a photograph taken earlier of the same region. Normally, these photos would be roughly the same. Certain objects, such as planets, may have changed position relative to the background stars, and the brightness or size of the stars may appear different from night to night, but the arrangement of the stars relative to each other generally does not change over a period of nights, years or even centuries.

A supernova could be an explanation for seeing a new star. The term comes from the Latin word "nova" meaning new, though ironically a supernova is actually the event associated with the death of a star. Astronomers have studied various types of supernovae and have created possible explanations for the processes that could cause such events. Certain types of supernovae can give important clues to the puzzle of the age, size and fate of our universe, as well as contribute to our evolving understanding of the structure of stars.

Although the study of supernovae is a very active field in astronomy, theories are constantly being challenged about the different types of supernovae and the stars that produce them. Currently more than sixty supernovae are discovered each year, but often times they are sighted after the maximum peak of the light curve so some of the scientific information is lost.

Astronomers have classified supernovae into two kinds, Type I and Type II, based on the amount of hydrogen observed in the material surrounding the explosion of the star. Type I have no observed hydrogen, leading astronomers to believe the outside layers were already shed. Hydrogen is observed from Type II supernovae so they are generally believed to be explosions of higher mass stars. This theory is consistent with the fact that Type II supernovae are only found in spiral galaxies, and usually in the arms, where high-mass star formation is thought to be more prevalent, whereas Type I supernovae are found in both spiral and elliptical galaxies.

Most elements heavier than hydrogen and helium are predominantly created inside stars or in the process of the supernova explosion itself. These elements are ejected into space by supernovae and then reused to form new stars and planets such as the Earth. The atoms that make up almost every substance that you deal with everyday, including the chair you are sitting in, the food you eat, and even your body itself, were once inside a star. You are made up of star matter.

Type I Supernovae

Most stars in the universe are found in multiple star systems, meaning that two or more stars are in a gravitational orbit around a common center point. When these stars are very close together the material from one star can spill over onto another star, greatly effecting the evolutionary process of each star. Current theories suggest that Type I supernovae occur in binary systems containing a white dwarf and a massive star.

A white dwarf is the very compact remnant of a low mass star that has burned up all the hydrogen and helium in its core leaving a very dense remnant of mostly carbon. The outer layers of unburned hydrogen were blown off during a burst of helium fusion that created a planetary nebula around the white dwarf. A white dwarf is always less than 1.4 times the mass of the Sun. Any additional mass will cause the white dwarf to collapse and create a different type of remnant called a neutron star.

When a white dwarf is part of a binary, mass can be exchanged between the white dwarf and its companion. Each star has an imaginary shell around it within which all matter is gravitationally bound to that star. Astronomers refer to these regions as the Roche lobes for the binary system (see figure 1). As the companion star evolves, its radius will expand due to thermal pressure. This may cause some of its outer material to overflow its Roche lobe and fall onto the white dwarf. The white dwarf gains more and more mass by this method until it reaches the critical threshold of 1.4 times the mass of the Sun, where it can no longer support itself. In a violent implosion, called a Type Ia supernova, the white dwarf succumbs to the increased pressure and, in turn, heats up to the point where it can burn fuel again. This time the fuel is carbon. The ignition of the fuel results in a tremendously bright flash, which then fades over a period of days or weeks. Discoveries of these supernova have been made out to the edge of the visible universe.

The critical threshold of 1.4 times the mass of the Sun is the same for all white dwarfs. This means that no matter what the mass or temperature was for the original star, it will implode with the same amount of fuel left to burn. Since the mechanism for ignition is the same and the amount of fuel is the same, it follows that the luminosity resulting from the rapid ignition is the same for all white dwarfs undergoing a Type Ia supernova. Astronomers call such an object a "standard candle", meaning that its luminosity is known so we can use it as a point of reference from which to compare other objects. We can observe the apparent brightness of the supernova as seen from earth, and knowing its absolute brightness as a standard candle, we can then determine its distance away from us.

Type I supernovae are often categorized as Type Ia, Type Ib, or Type Ic supernovae. The different letters refer to differences in the specific elements detected after the explosion and the rate at which its brightness fades. Theories that attempt to explain the differences among the various categories of Type I supernovae focus on the specific mass of the original star. It is thought that a Type Ib or Ic supernova may be caused by the remnant of a very high mass star, such as a neutron star that is part of a binary system.

Type II Supernovae

High mass stars undergo even more violent explosions called Type II supernovae (see figure 2). High mass stars achieve much higher temperatures inside so they are able to burn heavier elements than low mass stars. A very dense core of iron builds up within the center of the star as a result of the burning, with the lighter elements in the surrounding layers. This configuration is sometimes referred to as an onionskin model because of the spherical shells of various elements.

Through energy-producing nuclear fusion, only elements as heavy as iron can be produced. Any nuclear reactions producing heavier elements require an input of surplus energy. Therefore the star only continues to burn fuel until iron is produced in the core and then fusion stops. After the fuel runs out, the core cools to the point where the gravitational pressure causes the star to come crashing in on itself. The implosion is so strong that the outer layers of the star crash into the hard iron core and bounce back out with tremendous energy. This is called a shock wave. The shock wave ignites the material in the outer layers of the star and the result is a sudden explosion that can be one billion times as bright as the original star. The remnant of the core of a Type II supernova will either be a neutron star or a black hole, depending on the original mass of the star.

The intense brightness of a Type II supernova is caused by the burning of the lighter elements that are in the outer layers of the star. This material is thrust outward by the explosion creating an expanding bright nebula or halo that can remain visible for thousands of years. The explosion releases such tremendous amounts of energy that the surplus energy required for nuclear fusion of elements heavier than iron is available. In fact, it is believed that supernova explosions may be responsible for the creation of all material heavier than iron or at least for providing "seed" iron elements that are the fuel for further nuclear and chemical evolution. This includes elements such as lead, zinc, gold, and silver.

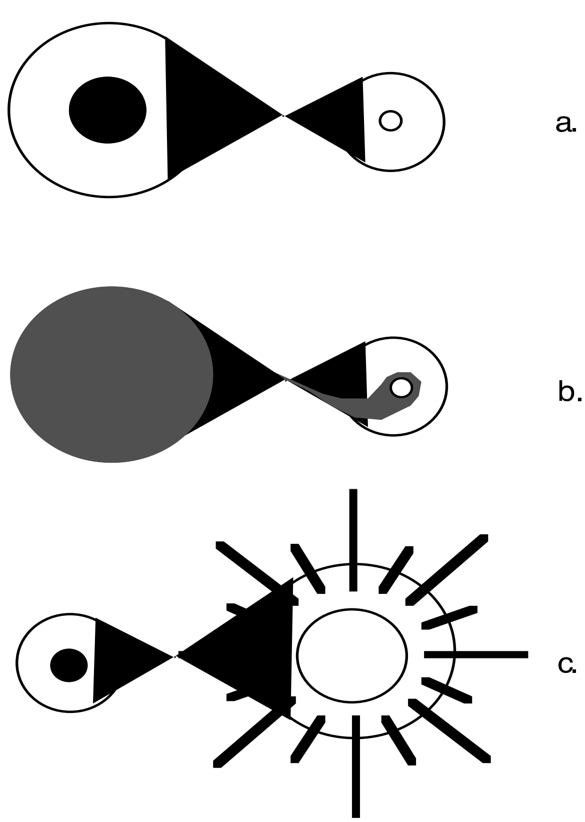


Figure 1
a) A star and its companion white dwarf within their Roche lobes.
b) The star bloats into a red giant and its outer layers overflow the Roche lobes. The overflowing matter falls onto the surface of the white dwarf.
c) The white dwarf implodes and ignites fusion causing a bright flash called a Type I supernova

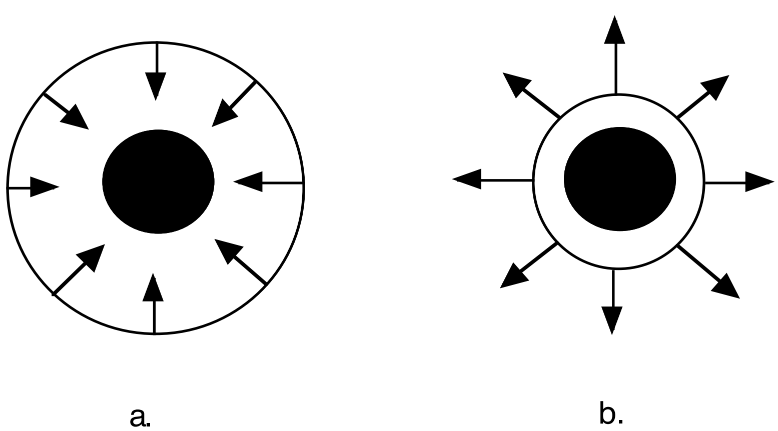


Figure 2:
a) In a Type II supernova the outer layers of a high mass star come crashing in and
b) bounce off the dense core sending a shock wave outward.